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A NOTE ON ESTIMATING CONTINUOUS TIME DECISION MODELS.(U)
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A NOTE ON ESTIMATING CONTINUOUS TIME DECISION MODELS

by

R. P. Trost, Philip Lurie and Edward Berger*

1. INTRODUCTION

Continuous time decision models have a long history in economics. In fact, the early work of Mincer [1962] implies that a woman's labor force participation decision is made with a *continuous time horizon* in mind. More recently, Mincer and Polacheck [1974 and 1978], Mincer and Ofek [1980], and Sandell and Shapiro [1978] analyze the length of time women remain out of the labor force. Sandell [1977] examines the determinants of the number of years women work after the birth of their first child, and in a stock adjustment model of fertility decisions, Hyman [1980] examines the length of time between births. There are also several studies that seem suited to continuous time analysis but are estimated with discrete time choice models. For example, Shapiro and Mott [1979] estimate a discrete time choice model of women's post child labor force participation rates. One could also analyze post child labor force participation, as Mincer and Polacheck [1974] do, by looking at a woman's interval of nonlabor force participation following the birth of a child.

All of the above studies choose (or imply) as the dependent variable of interest some measure of continuous time, whether it be in percentage terms or actual years. In some of these papers (e.g., Mincer and Polacheck [1974] and Hyman [1980]) this dependent variable is studied by looking at its mean

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*We would like to thank Robert Dorfman, Jacob Mincer and Solomon Polacheck for comments on earlier versions of this paper. Any remaining errors are our own responsibility.

value (actual or predicted) in various age and education subgroups. In other studies (e.g., Mincer and Ofek [1980] and Shapiro and Mott [1979]) the determinants of the dependent variable are estimated with regression analysis. While the estimation of continuous time models is a step in the right direction (away from discrete time choice models), the purpose of our note is to point out that the empirical results in these otherwise excellent theoretical papers may be biased. The source of this bias lies in the way censored observations are handled in the empirical analysis. The rest of the paper is divided into the following sections. In Section Two we discuss a potential source of bias in previous studies. In Section Three we propose an alternative method for estimating time decision models and in Section Four, we consider two different applications of this method. Section Five contains the conclusions.

II. A SOURCE OF BIAS: CENSORED OBSERVATIONS

All the studies cited in the introduction derive and estimate life cycle decision models. One variable of interest in these papers is some sort of "length of time" variable. For example, Mincer and Polacheck [1974] study, among other things, the length of time women remain out of the labor force following the birth of the first child. Mincer and Ofek [1980] estimate the determinants of a woman's duration of unemployment. Hyman [1980] estimates a stock adjustment fertility model where one variable of interest is the length of time between children[1] (i.e., childspacing). The authors'

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[1] Although Hyman's theoretical interest include the decision regarding the desired <u>spacing between children</u>, his actual empirical analysis only looks at the proportion of respondents who had one child during the following year, given that they desired to have one more child. However, child spacing in the usual meaning of the word is implied in his paper and is worth investigating.

justification for studying these dependent variables is well founded in economic theory, and we have no quarrel with their theoretical models. Our concern is with the empirical section and in particular with the manner in which censored observations are handled in the analysis. A simple example will demonstrate our point.

Suppose we want to estimate the average length of time women wait before returning to work following the birth of their first child. For simplicity, assume we have a sample of ten women who all gave birth on the same day. Let the observations y_i be:

$$1, 1, 2, 2, 3, 3, 4, 4, 5, 5$$

where y_i is the number of years elapsed before the women return to work. If we analyze these data five years after the children are born, we can simply average the ten observations y_i to get an unbiased estimate of the mean. Suppose, as is often the case with panel data, we do not have "completed" values of y_i for all the observations. This would be the case, for example, if we have data for only the first three years following the birth of these children. In this case we will have six observations where the length of time is observed (1,1,2,2,3,3) and four where the length of time is censored (the values 4, 4, 5, 5 which of course are unobserved) at 3 years. Here the term censored means that all we know is these four women wait at least three years before returning to work. If we simply average the six uncensored observations, we will underestimate the mean of y_i. Even if we include the censored observations and enter a value of "3" for them, we will still underestimate the mean value of y_i. These same problems exist if we wish to use regression analysis to measure the impact of an exogenous variable X_i

on y_i, i.e., we will underestimate $E(Y_i|X_i)$. Despite these obvious biases, it is surprising that none of the previously cited papers discuss (or take account of) this "censored data" problem. As we show in the next section, there is a simple method for handling this problem, that to our knowledge has never been applied to economic data.

III. A METHOD FOR ESTIMATING CONTINUOUS TIME MODELS WHEN THE DATA ARE CENSORED

The estimation of continuous time models have a long history in the biostatistical literature. They have been used extensively in the biomedical sciences in the general area of patient survival. Here the problem has been to estimate the probability that a patient survives beyond time T. A plot of these probabilities as a function of time, i.e.,

$$S(t) = P(T > t), \qquad (1)$$

is called a "survival curve."

Kaplan and Meir [1958] were the first to derive a nonparametric maximum likelihood estimate of the true survival function in the presence of censoring. However, the Kaplan-Meir method only estimates "unadjusted" survival curves. That is, the survival curves are not adjusted for exogenous characteristics. It was not until 1972 that a nonparametric method became available for handling censored observations while adjusting for factors (i.e., exogenous variables) which may affect the probability of survival. This method was first proposed by Cox [1972] and is known as the Cox Regression model. The Cox model expresses a hazard function[2] as

[2]The hazard function h(t), is defined as the conditional probability of a failure in the interval (t,t+dt), given survival to time t. That is,

$$h(t)dt = P(t \leq T \leq t+dt \mid T \geq t).$$

$$h_Z(t) = h_0(t)e^{\beta' Z},$$

where Z is a vector of exogenous variables, β is a vector of unknown coefficients and $h_0(t)$ is assumed fixed and independent of Z, but otherwise completely unspecified. Note that $h_0(t)$ corresponds to the hazard function for the situation when Z = 0. The survival function $S_0(t)$ refers to the case where the exogenous variables Z = 0 and is expressed as

$$S_0(t) = e^{-\int_0^t h_0(X)dX} .$$

Since the model assumes proportional hazards i.e., the hazard ratio for any two values of Z is independent of time, then

$$S_1(t) = (S_0(t))^{e^{\beta' Z_1}} ,$$

where $S_1(t)$ is the survival curve for an individual with exogenous variables Z_1. Cox [1972] shows how to estimate the vector β and the function $h_0(t)$ with a maximum likelihood approach.

In the next section we demonstrate the usefulness of the Cox Regression technique by estimating an unemployment duration equation and a childspacing equation.

IV. TWO EMPIRICAL EXAMPLES WITH CENSORED OBSERVATIONS

In this section we demonstrate the feasibility of the Cox model with two empirical examples. The first application estimates an equation where the dependent variable is a woman's duration of unemployment following the birth of her first child. The second application concerns the length of time a family waits before having their first child.

A. Duration of Unemployment

As we noted earlier, many have studied the labor force participation decisions of women. Some, like Nelson [1977] and Heckman and Willis [1977] study it in the context of discrete time, while others like Mincer and Ofek [1980] analyze it in continuous time. In the present paper we show how the Cox regression model can be used to estimate the probability that a woman returns to work (following the birth of her first child) after one year, two years, three years, etc. This method takes account of the censored observations in the sample and will yield an unbiased estimate of the mean duration. We use the 1973 wave of the Parnes NLS data on young women to estimate the unemployment duration equation. Table 1 gives mean values for the six exogenous variables and the mean value of unemployment duration (the dependent variable). Note that by ignoring the fact that 79 of the duration observations are censored, one would underestimate the mean duration of unemployment for these women by 16 percent. A consistent estimate of mean duration is 3.25 and is easily calculated from $E(T) = \int_0^\infty S(t)dt$.

Table 2 gives the maximum likelihood estimates for the Cox model. To see how these coefficients are interpreted, recall that the Cox model expresses a "survival" curve as:

$$S(t) = (S_0(t))^{\exp(\beta'X)} \qquad (2)$$

Consequently, a positive sign on the coefficient for exogenous variable Z means that as Z is larger, the women will decide to go back to work sooner. A negative sign means that as Z is larger, the women will wait longer before returning to work.

TABLE 1

DEFINITION AND MEAN OF VARIABLES

Variable	Mean	Definition
Dependent variable	3.25*	Defined in table 2
EDUC	11.95	Wife's education
HUSINC	$9274.55	Husband's income
DSMSA	.39	Dummy = 1 if in SMSA
DRACE	.245	Dummy = 1 if nonwhite
UNEMP	7.7	Unemployment rate of county
Age	19.54	Age of women when child was born

*This mean takes account of the censored values. It is calculated as the area under the survival curve. If we calculate a simple mean of the 212 observations we get a value of 2.72. Hence, by ignoring the censoring problem we underestimate the duration of unemployment by 16 percent.

TABLE 2

COEFFICIENT ESTIMATES IN THE COX REGRESSION MODEL

(Dependent Variable = Length of time to re-entering the labor force after having first child)

Variable	Coefficient	Standard deviation	χ_1^{2*}
EDUC	.1354	.0674	4.036
HUSINC	-.0000265	.0000206	1.654
DSMSA	.1326	.1878	.499
DRACE	.0586	.2092	.078
UNEMP	-.0127	.0155	.667
AGE	-.02195	.0465	.223

Log likelihood (all Betas = 0) = - 650.25
Log likelihood (all MLE) = - 647.09
Number of observations = 212
Number of censored values = 79

*Using a significance level of .05, any χ_1^2 value greater than 3.84 is considered significant.

For the coefficients in Table 2 then, we see that as the woman's education increases, she will go back to work sooner. As her husband's income, her age or the unemployment rate increase however, she will wait longer before returning to work. The only significant coefficient at the .05 level is the education variable.

To see what effect education has on the time at which a woman returns to the labor force, recall that "survival" in our model means a woman did not go back to work by time t. Column 2 of Table 3 gives the survival probabilities for exogenous variables $\bar{Z}_1$ = (1) EDUC = 12, (2) HUSINC = \$9200, (3) DSMSA = 0, (4) DRACE = 0, (5) UNEMP = 77, and, (6) AGE = 19.5. Column 3 of Table 3 gives the survival probabilities for exogenous variables $\bar{Z}_2$, where $\bar{Z}_2$ is the same as $\bar{Z}_1$ except EDUC = 16 rather than 12. Table 3 tells us that the probability of a woman with characteristics $\bar{Z}_1$ of not going back to work within 2 years is .63. For a woman with characteristics $\bar{Z}_2$, this probability is .45.

B. Childspacing Equation

A second example that demonstrates the usefulness of the Cox technique in the estimation of economic decision equations is found in the work of Hyman [1980]. One variable of interest in Hyman's paper is childspacing, where he defines "childspacing" as the proportion of respondents who had one child during the following year, given that they desired to have one more child. In our paper we define childspacing as the length of time between children and estimate an equation where the dependent variable is the length of time women wait before having their first child. We again use the 1973 wave of the Parnes NLS data on young women. The dependent variable will be censored for those couples who did not have their first child by 1973. To handle this

TABLE 3

SURVIVAL* PROBABILITIES EVALUATED AT $\overline{Z}_1$ AND $\overline{Z}_2$

Time	Survival at $\overline{Z}_1$	Survival at $\overline{Z}_2$
0	1.00	1.00
1	.75	.61
2	.63	.45
3	.51	.32
4	.44	.24
5	.38	.19
6	.34	.16
7	.29	.12

$\overline{Z}_1$: (1) EDUC = 12, (2) HUSINC = \$9200, (3) DSMSA = 0, (4) DRACE = 0, (5) UNEMP = 77, and, (6) AGE = 19.5

$\overline{Z}_2$: Same as $\overline{Z}_1$, except EDUC = 16.

*Surviving to time t is defined as not returning to work by (i.e., to <u>and</u> including) time t.

censoring problem, the Cox regression model is a natural choice of estimation techniques and is the one we use. Table 4 gives the maximum likelihood estimates.

For the coefficients in Table 4 we see that as the wife's age, education, or IQ increases, or as husbands income goes up, the couple will wait longer before having the first child. Also, Table 1 tells us that couples who live in rural regions will wait longer than similar couples who live in urban areas before having the first child. However, the only significant coefficients are the education and income coefficients.

For this application "survival" means the family did not have a baby by any given time t. Column 2 of Table 5 gives the "survival" probabilities for exogenous variables $\bar{Z}_1$: (1) Age = 20, (2) Dummy Rural = 0, (3) IQ = 100, (4) Educ. = 12, and, (5) Income = \$5,000. Column 2 tells us that probability of not have a child by two years is .425. A similar interpretation holds for the rest of column 2 in Table 5.

Column 3 of Table 5 gives the "survival" probabilities for exogenous variables $\bar{Z}_2$:$\bar{Z}_2$ is the same as $\bar{Z}_1$, except income = \$10,000 rather than \$5,000. Notice that the probabilities are uniformly (because of proportional hazard) higher for $\bar{Z}_2$. This means that as income goes up (from \$5,000 to \$10,000), couples wait longer before having the first child. The probability of not having a child by any given year is greater for couples with husband's income of \$10,000 than it is for similar couples with husband's income of \$5,000. A similar interpretation holds for Column 4 of Table 5.

In this section we gave two examples of how the Cox model can be used to estimate economic time decision models. Our purpose in this empirical section was not to re-do previous studies, but to demonstrate the applicability and feasibility of the Cox regression technique. It is also hoped that we make others aware of the censored data problem in future analyses.

Table 4

Coefficient Estimates in the
Cox Regression Model

(Dependent Variable = Number of Years* Before
Having First Child)

Variable	Coefficient	Standard Deviation	X^2**
Age at marriage	-.000218	.0267	0.00
Dummy (=1 if Rural)	-.1072	.0873	1.51
IQ of Wife	-.0014	.0031	.21
Education of Wife	-.08899	.0308	8.37
Husband's Annual Income	-.000064	.000015	17.73

Log Likelihood (all Betas = 0) = -3692.19

Log Likelihood (at MLE) = -3671.59

Number of observations = 681

Number of couples having a child = 620

Number of censored values = 61

*Since we only had annual data, our dependent variables took on discrete values 1, 2, 3, etc. Of course, the Cox model can easily handle a continuous dependent variable.

**All X^2 are with 1 degree of freedom. Using a significance level of .05, any X^2 value greater than 3.84 is considered significant.

Table 5

Survival Probabilities Evaluated at
$\bar{Z}_1$, $\bar{Z}_2$ and $\bar{Z}_3$

Time	Survival* at $\bar{Z}_1$	Survival* at $\bar{Z}_2$	Survival* at $\bar{Z}_3$
0	1	1	1
1	.589	.681	.667
2	.425	.537	.519
3	.276	.393	.373
4	.194	.304	.285
5	.156	.260	.241
6	.119	.213	.196
7	.080	.160	.144
8	.073	.150	.135
9	.064	.136	.122
10	.044	.104	.091
11	.044	.104	.091

$\bar{Z}_1$: (1) Age = 20, (2) Dummy Rural = 0, (3) IQ = 100, (4) Education = 12, (5) Husband's Annual Income = $5,000.

$\bar{Z}_2$: Same as $\bar{Z}_1$, except husbands annual income = $10,000.

$\bar{Z}_3$: Same as $\bar{Z}_1$, except Education = 15.

*"Surviving" to time t is defined as not having a baby by (i.e., up to and including) time t.

V. CONCLUSIONS

In this paper we pointed out a potential source of bias in the estimation of continuous time decision equations. This bias will exist whenever there are censored observations in the data and estimation techniques such as least squares are used. To correct for this bias one has to use an estimation technique, such as the Cox regression model, which takes censored observations into account. We demonstrated the usefulness of the Cox model by estimating an unemployment duration equation and a childspacing equation. We think that the Cox model performs adequately and yields reasonable estimates.

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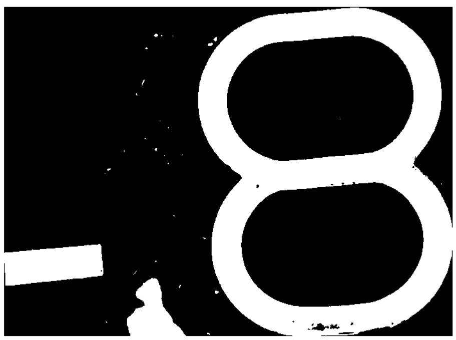
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